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# RESEARCH MEMORANDUM

## A BRIEF INVESTIGATION OF THE EFFECT OF WAVES ON THE TAKE-OFF RESISTANCE OF A SEAPLANE


By Elmo J. Mottard

Langley Aeronautical Laboratory
Langley Field, Va.


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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

April 24, 1956


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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

# A BRIEF INVESTIGATION OF THE EFFECT OF WAVES ON THE TAKE-OFF RESISTANCE OF A SEAPLANE

By Elmo J. Mottard

## SUMMARY

The resistance of a model of a seaplane with a length-beam ratio of 15 and a wing loading of 120 pounds per square foot was determined in smooth water and three wave heights under various conditions of load, speed, elevator setting, angle of dead rise, and center-of-gravity position. In general, the resistance was greater in waves than in smooth water and increased with wave height. The maximum increase due to waves occurred at speeds between hump speed and take-off. In 6-foot waves the maximum increase was 65 percent at a speed equal to 70 percent of getaway speed. The effect of waves on resistance was about the same for dead-rise angles of 20°, 40°, and 60°.

## INTRODUCTION

During take-off in smooth water it is usually possible to operate a seaplane at trims which give maximum lift-drag ratios at all but the low-speed portion of the run. In waves, however, departures are made from these favorable trims during the uncontrollable motions which the seaplane goes through. During these motions the water load and wetted length-beam ratio may become very large; also, spray may become very high, wetting aerodynamic surfaces which would normally be dry. The extent to which these factors increase the resistance is not known.

In order to determine the order of magnitude of the resistance increase, exploratory tank tests were made with a dynamic model of a possible seaplane design. The controlled variables of the investigation included speed, elevator deflection, center-of-gravity location, load, angle of dead rise, and wave height and length. A high wing loading was used so as to have the range of water speeds correspond with that of a high-speed water-based aircraft. The total average horizontal force required to maintain speed was measured for various speeds up to take-off in waves corresponding to 2, 4, and 6 feet high full-size.

## SYMBOLS

$\tau_i$ instantaneous trim (angle between forebody keel at step and horizontal reference line), deg

$\tau$ average trim, $\dfrac{\int \tau_i \, dt}{t}$, deg

$r_i$ instantaneous rise (distance of the point of the step above the static water surface), ft

$r$ average rise, $\dfrac{\int r_i \, dt}{t}$, ft

$C_r$ average rise coefficient, $\dfrac{r}{b}$

$R$ average total resistance including air drag, lb

$C_R$ average total-resistance coefficient, $\dfrac{R}{wb^3}$

$b$ beam, ft

$t$ elapsed time interval, sec

$V$ speed, ft/sec

$C_V$ speed coefficient, $\dfrac{V}{\sqrt{gb}}$

$\bar{c}$ mean aerodynamic chord, ft

$C_{\Delta_o}$ gross-load coefficient, $\left(\dfrac{\Delta_o}{wb^3}\right)$

$\Delta_o$ gross load, lb

$g$ acceleration due to gravity $\left(32.2 \text{ ft/sec}^2\right)$

$w$ specific weight of water (63.4 lb/cu ft for these tests)

$C_{V_G}$ speed coefficient at getaway

## MODEL AND APPARATUS

The basic model, which is shown in figure 1(a), was a 1/12-size dynamic model of a possible seaplane design having a gross load of 75,000 pounds, a beam of 5.84 feet, a wing loading of 120 pounds per square foot, a length-beam ratio of 15, and a dead-rise angle of 20°. This seaplane was similar to that described in reference 1 except that a smaller wing was used giving a wing loading 3 times as great. The model was tested with dead-rise angles of 40° (fig. 1(b)) and 60° (fig. 1(c)). The high length-beam ratio of 15 and the wing loading of 120 pounds per square foot are representative of current values for high-speed seaplane designs.

The apparatus, which is shown schematically in figure 2, permitted movement of the model in the pitch, rise, and fore-and-aft directions. The mass of the moving parts was kept at a minimum so that their inertia would be small, and the spring constant $\left(\frac{\text{Force}}{\text{Deflection}}\right)$ of the rubber spring which was used to simulate propeller thrust was made as small as was practical so that variations in towing force during fore-and-aft movement of the model would be small. The tests were made using the Langley tank no. 1 towing carriage, which is described in reference 2. The wave-making machine is described in reference 3.

## PROCEDURE

The basic conditions were: elevator deflection, 0°; speed coefficient, 10.1 $\left(0.7C_{V_G}\right)$; center-of-gravity location, $0.36\bar{c}$; gross-load coefficient, 5.85; angle of dead rise, 20°; wave length, 180 feet full scale. Variations of each of these conditions were tested in smooth water and in waves corresponding to 2, 4, and 6 feet high.

The model was first accelerated to a constant speed; then the spring tension was adjusted to keep the model within its permitted range of fore-and-aft movement. When this equilibrium was established the speed, spring tension, trim, and rise were recorded. The spring tension was a direct measure of resistance.

The average resistance was obtained from the records by direct measurement without the need for any averaging process because the spring tension remained essentially constant. This was so because of the low spring constant, which resulted in the application through the dynamometer of a nearly constant towing force; the fluctuations in resistance caused by waves were overcome mostly by the inertia of the model. The trim and rise, however, fluctuated greatly, and the averages of these were obtained by dividing $\int \tau \, dt$ and $\int r \, dt$ (obtained by mechanical integration of the records) by the elapsed time $t$.

## RESULTS AND DISCUSSION

The results are presented in the form of plots defining the variation of average total-resistance coefficient, average trim, and average rise coefficients caused by changes in speed, elevator deflection, wave height and length, center-of-gravity location, dead rise, and loading. These data are presented in figures 3 to 8.

The average total resistance, trim, and rise in smooth water and in waves of various heights are shown plotted against speed coefficient in figure 3. At low speeds the influence of the waves was small because the model followed the wave contours with little angular or vertical motion relative to the water surface. At the higher speeds the wave impacts and rebounds caused the average values of resistance, trim, and rise to be higher than for smooth water and to increase progressively with wave height. The average rise coefficient in waves continued to increase to getaway, but the greatest effects on average resistance coefficient and trim occurred at intermediate planing speeds where it was observed that the most severe impacts and rebounds occurred. At a speed coefficient of 10.1 $\left(0.7C_{V_G}\right)$ the increase in resistance due to waves was 40 percent for the 2-foot waves and 65 percent for the 6-foot waves. Near getaway speed the observed severity of the motions and the average resistance decreased because the model was nearly airborne and only contacted the wave crests occasionally. Near getaway speed, the resistance in waves actually became smaller than in smooth water, probably because afterbody wetting in waves exists for only a short interval during each wave encounter.

The effect of elevator deflection on average resistance, trim, and rise in smooth water and in waves at a speed coefficient of 10.1, which is in the range of maximum wave effect, is shown in figure 4. In smooth water, porpoising occurred, causing the tests to be limited to the elevator range from $-15^{\circ}$ to $10^{\circ}$; but, in waves, elevator settings beyond

this range could be used without encountering divergent oscillations. In the larger waves the elevator range was limited by the violence of the wave impacts. As in the preceding figure, the waves generally increased the average resistance, trim, and rise. The elevator deflection corresponding to trim for minimum resistance remained in the range between $0^\circ$ and $10^\circ$ for smooth water and all the wave heights tested.

The effect of height-length ratio on resistance for waves of various heights at a length of 180 feet and various lengths at a height of 6 feet is shown in figure 5. For the range of height-length ratio covered by these tests (0.011 to 0.033) independent variations of height and length resulted in similar values of resistance for a given value of height-length ratio. This result suggests the possibility that the resistance, like the vertical accelerations, etc. (ref. 3), are primarily a function of the wave slope.

The effect of center-of-gravity location on the resistance in waves is shown in figure 6 to be rather small. Forward movement of the center of gravity increased the resistance slightly. In this figure, and also in figures 4 and 8, it is noticeable that the resistance during porpoising is usually about the same as in waves.

In figure 7 the resistance for 10.5 percent overload $\left(C_\Delta = 6.45\right)$ is compared with the resistance for the normal load $\left(C_\Delta = 5.85\right)$. An additional curve formed by adding 10.5 percent to the normal-load resistance is also included. These curves indicate that no significant additional effect of the waves due to overload is present.

The variation of resistance with dead rise for zero height-length ratio (smooth water) in figure 8 appears peculiar in that the resistance for $20^\circ$ and $40^\circ$ is very nearly the same, whereas the resistance for $60^\circ$ is much higher. These results, however, were checked by data (included in the figure) at zero height-length ratio obtained from another investigation, as yet unpublished, using the same models. According to an analysis based upon available data on prismatic planing surfaces in smooth water (refs. 4, 5, 6, 7, and 8) the $20^\circ$ and $40^\circ$ dead-rise models were operating very near best trim, and the small resistance increase associated with the increased dead rise, shown in figure 8, was caused by an increase in the best-trim planing resistance. A similar small increase in best-trim planing resistance occurs with the dead-rise increase from $40^\circ$ to $60^\circ$; the remainder of the disproportionately large resistance increase which actually occurred seemed to be attributable to a disadvantageous operating trim (considerably below best trim) and insufficient clearance between the afterbody and the wake of the forebody. Apparently efficient utilization of as high a dead rise as $60^\circ$ would require an overall design to permit a higher forebody running trim and a larger depth of step.

Of principal interest in figure 8, however, is the effect of waves on resistance. The trend toward an increase in resistance with wave height-length ratio is similar for all three dead-rise angles.

## SUMMARY OF RESULTS

For a model of a seaplane having a hull length-beam ratio of 15 and a wing loading of 120 pounds per square foot, the results of variations in wave height along with variations from a basic set of conditions [elevator deflection, $0^{\circ}$; speed coefficient, 10.1 $\left(0.7C_{V_G}\right)$; center-of-gravity location, $36\bar{c}$; gross-load coefficient, 5.85; angle of dead rise, $20^{\circ}$; and wave length, 180 feet] were as follows:

1. The greatest effect of waves on the average resistance and trim was found at intermediate planing speeds where the most severe impacts and rebounds occurred. For the model investigated, the increase in resistance at a speed coefficient of 10.1 $\left(0.7C_{V_G}\right)$ was 65 percent in 6-foot waves.

2. The elevator deflection corresponding to trim for minimum resistance remained in the range between $0^{\circ}$ and $10^{\circ}$ for smooth water and all wave heights tested.

3. The increment in resistance due to waves was primarily a function of the wave height-length ratio.

4. Variations in the center-of-gravity position had only a small effect on the resistance in waves.

5. No change in the effect of waves due to increase in gross load was found.

6. The trend toward increase in resistance with increase in height-length ratio was similar for dead-rise angles of $20^{\circ}$, $40^{\circ}$, and $60^{\circ}$.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 30, 1956.

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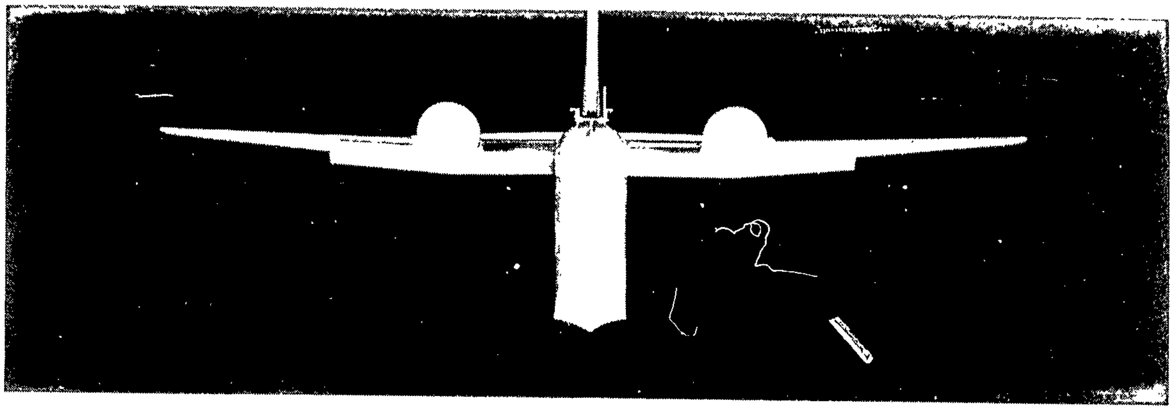

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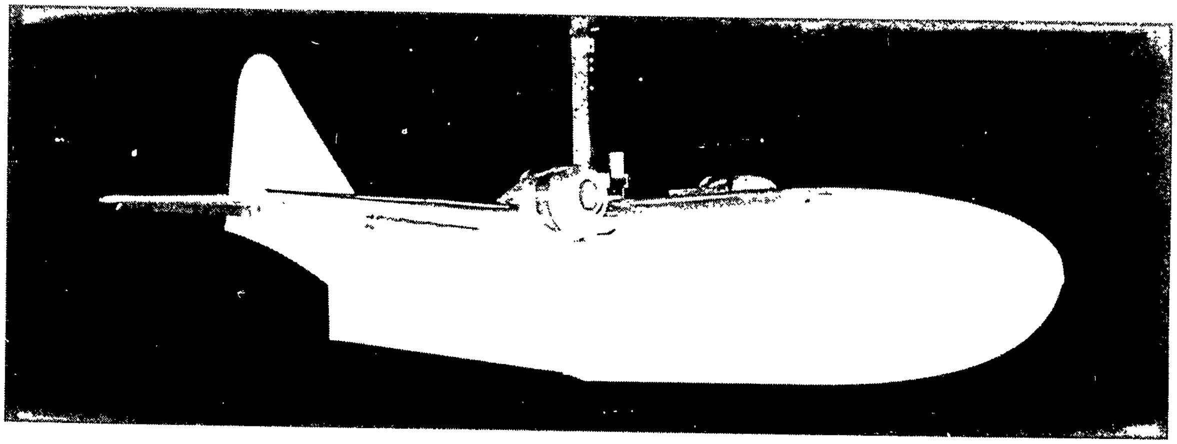

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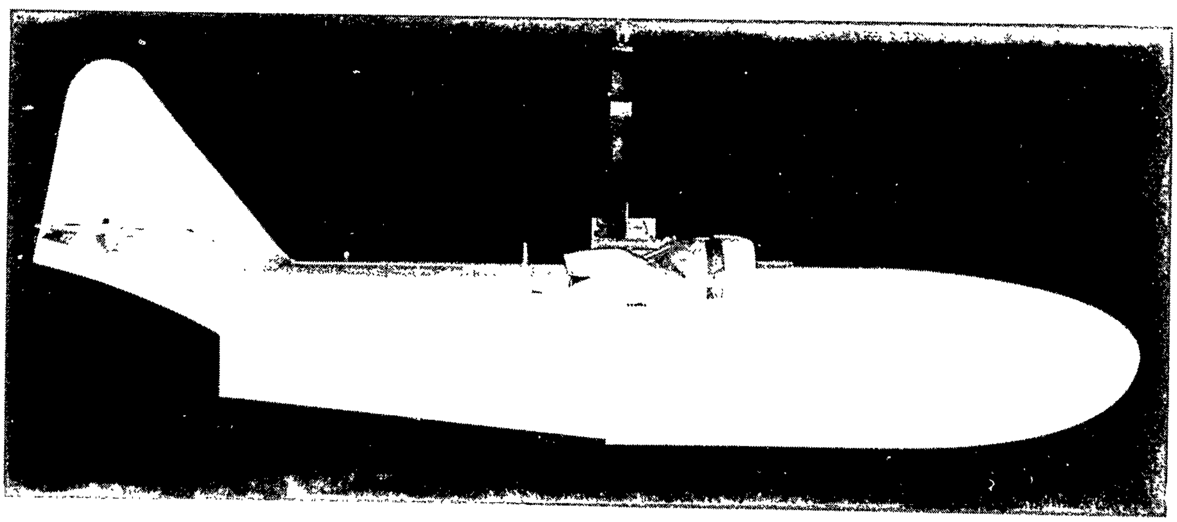
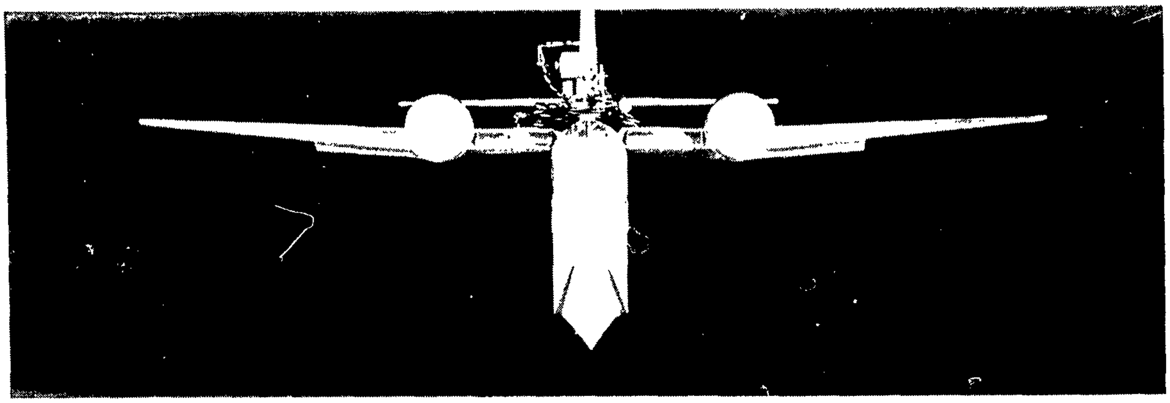


(a) Dead rise = 20°. L-83527

Figure 1.- The model with length-beam ratio of 15 and wing loading of 120 pounds per square foot.



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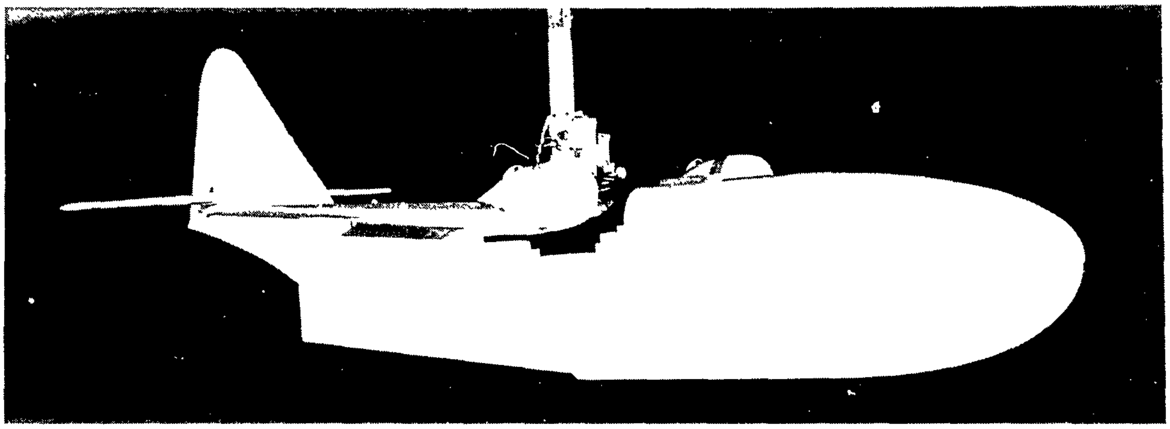

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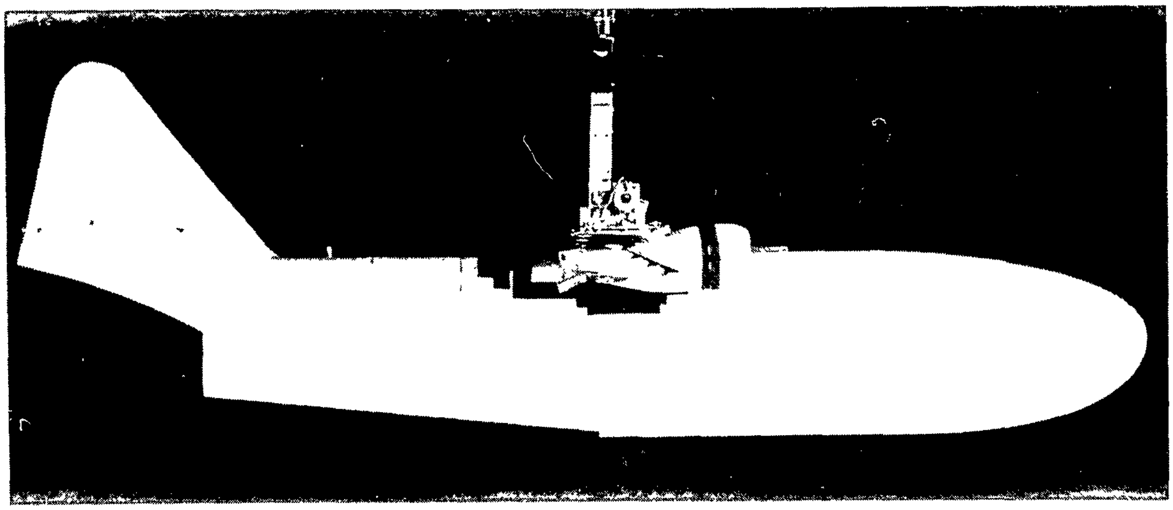
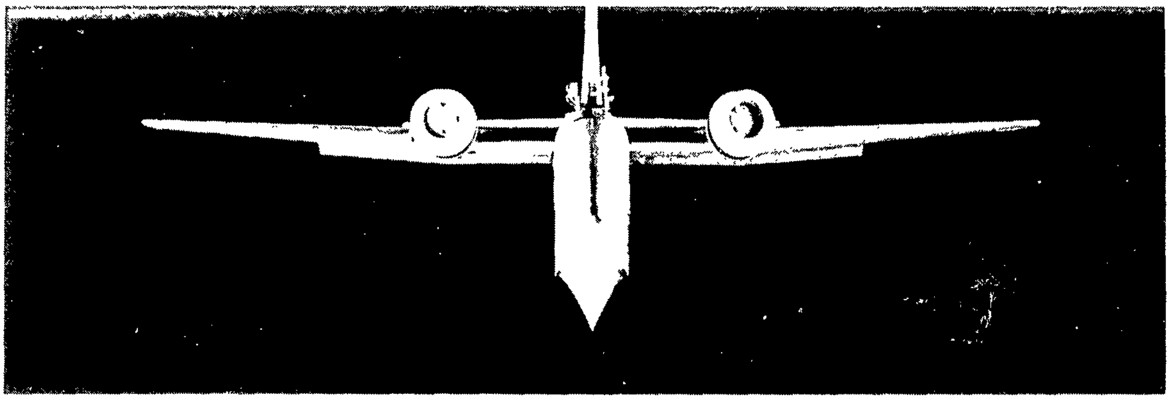


(b) Dead rise = $40^{\circ}$. L-83920

Figure 1.- Continued.



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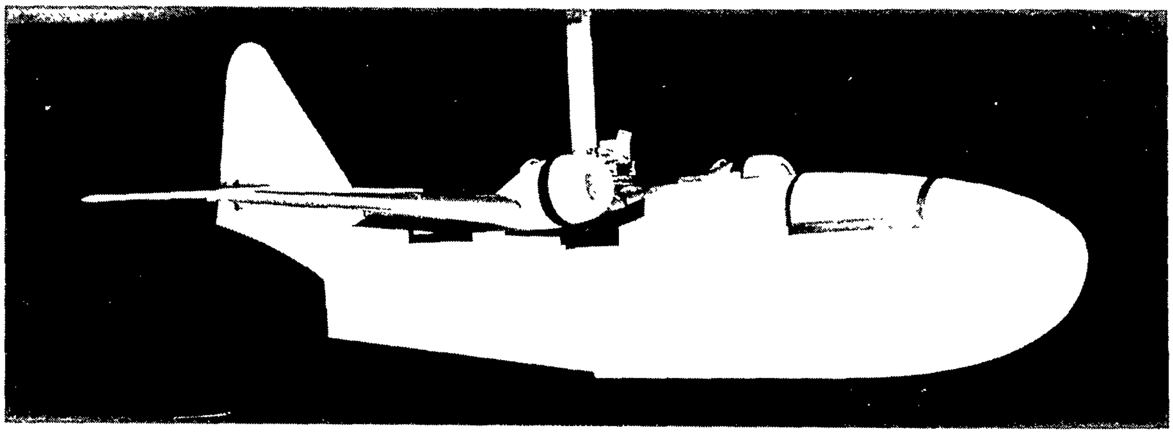

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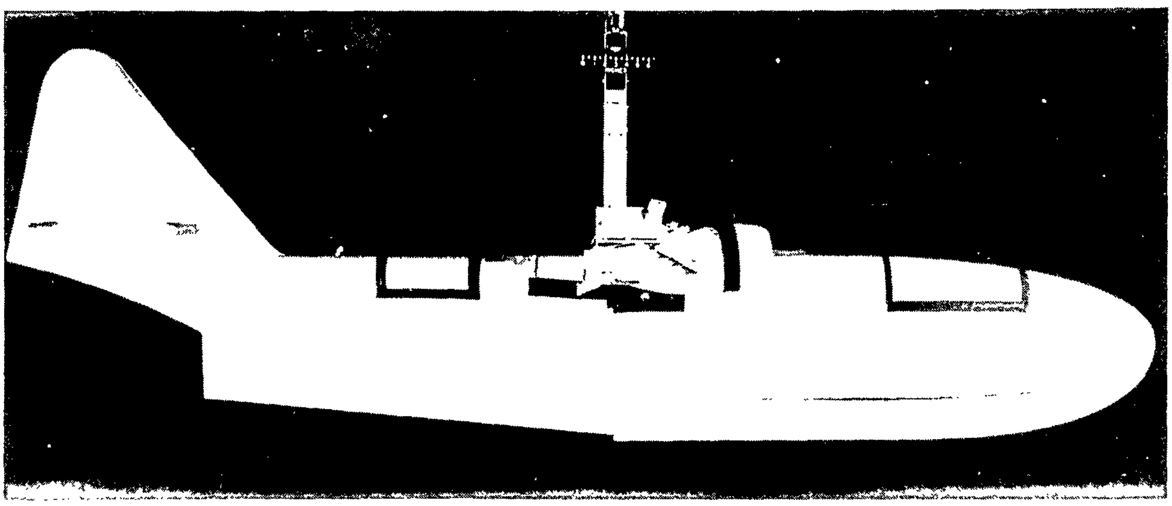

(c) Dead rise = 60°. L-84066

Figure 1.- Concluded.

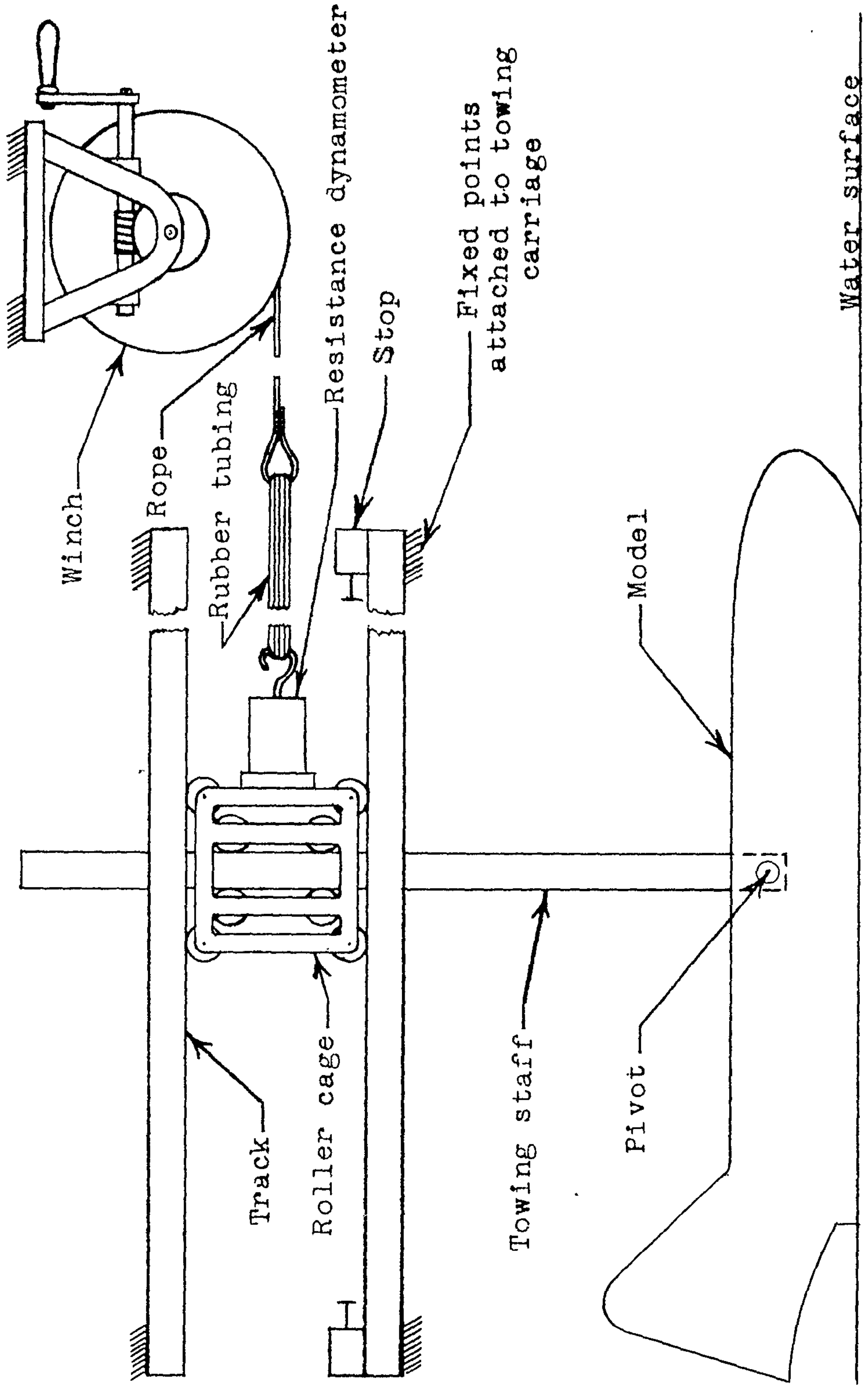


Figure 2.- Schematic of apparatus with model attached.

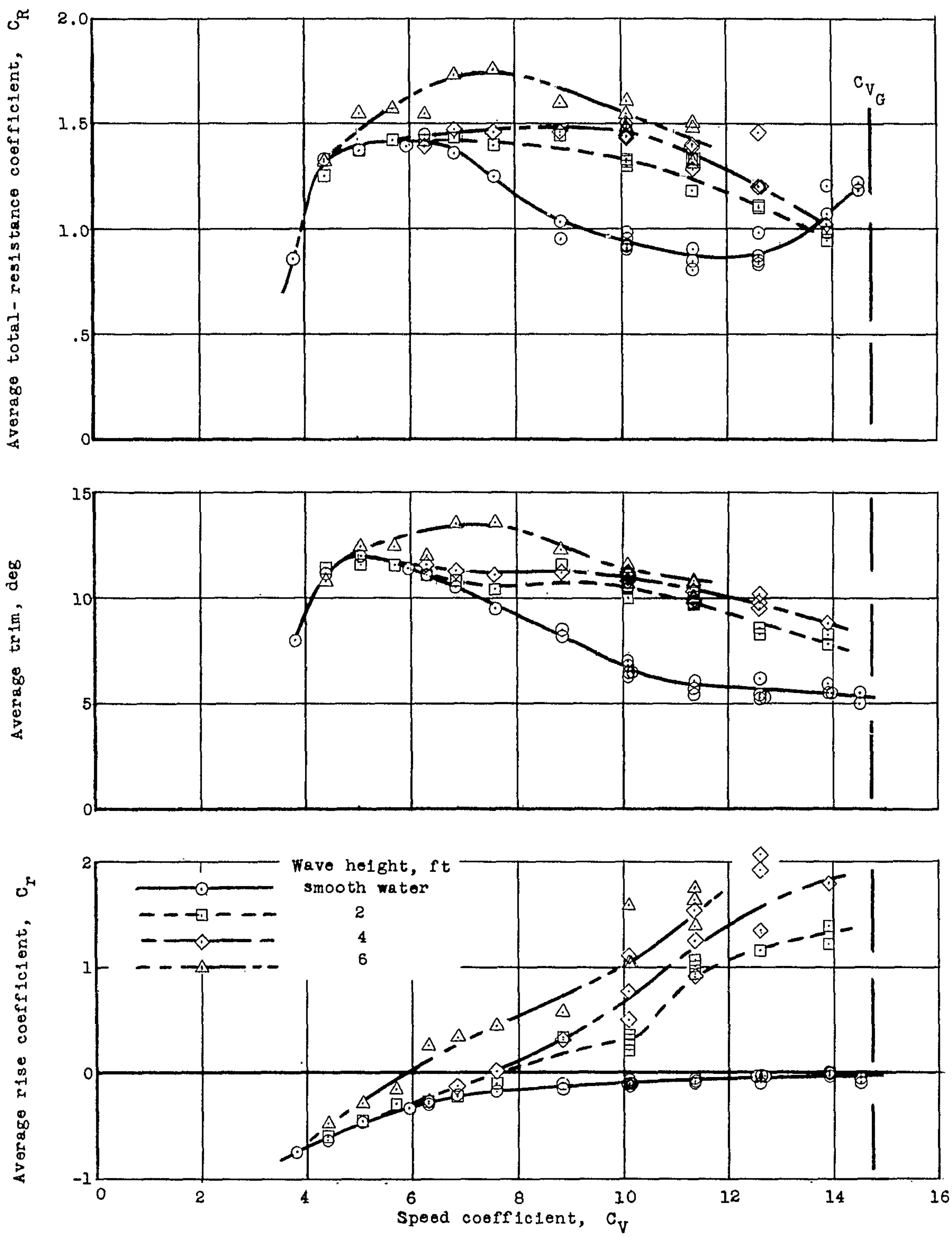


Figure 3.- The effect of speed on resistance, trim, and rise in smooth water and waves. Elevator deflection, 0°; center-of-gravity location, 0.36$\bar{c}$; angle of dead rise, 20°; gross-load coefficient, 5.85; wave length, 180 feet.

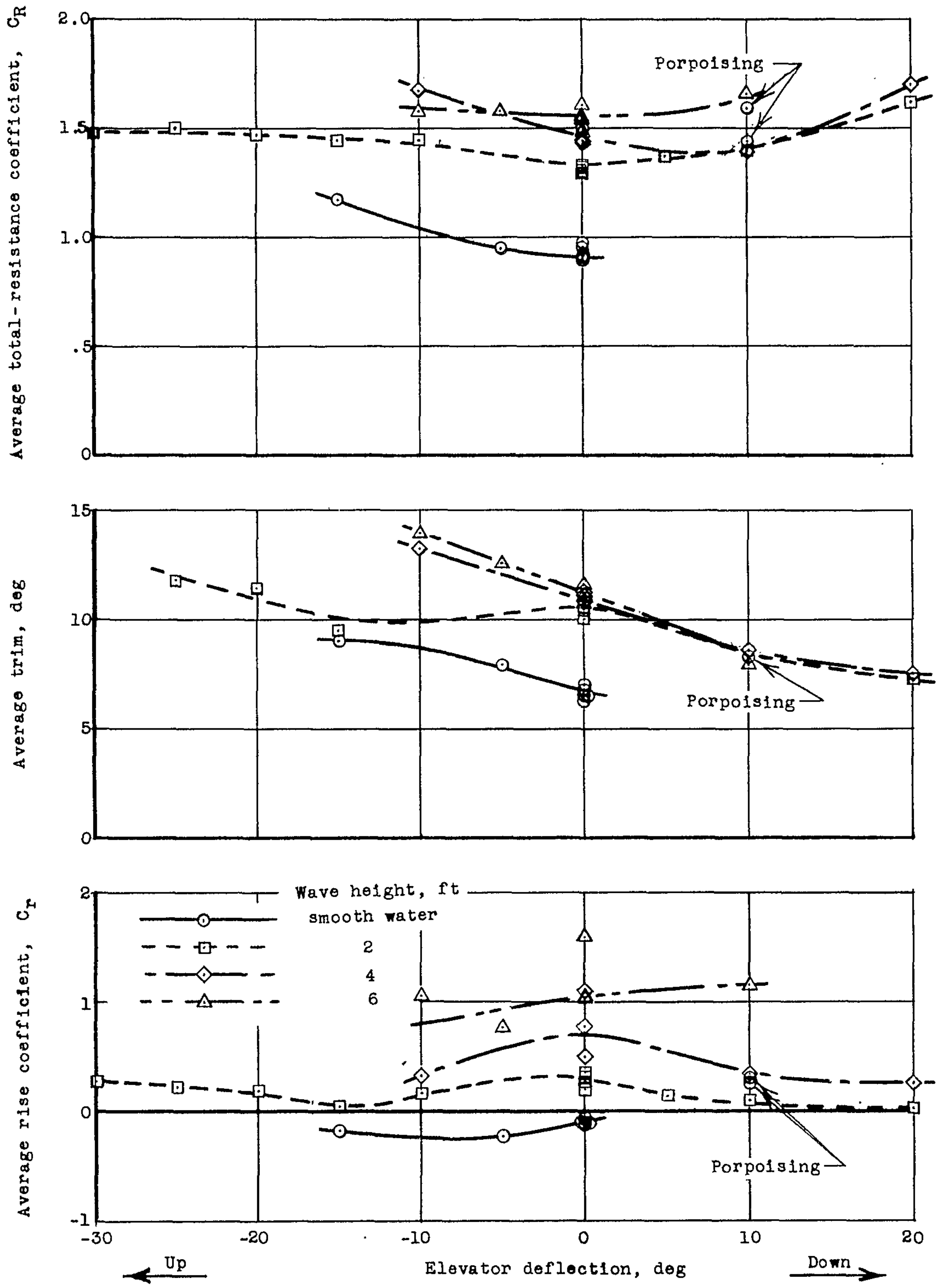


Figure 4.- The effect of elevator deflection on resistance, trim, and rise in smooth water and waves. Speed coefficient, 10.1, center-of-gravity location, $0.36\bar{c}$; angle of dead rise, $20^{\circ}$; gross-load coefficient, 5.85; wave length, 180 feet.

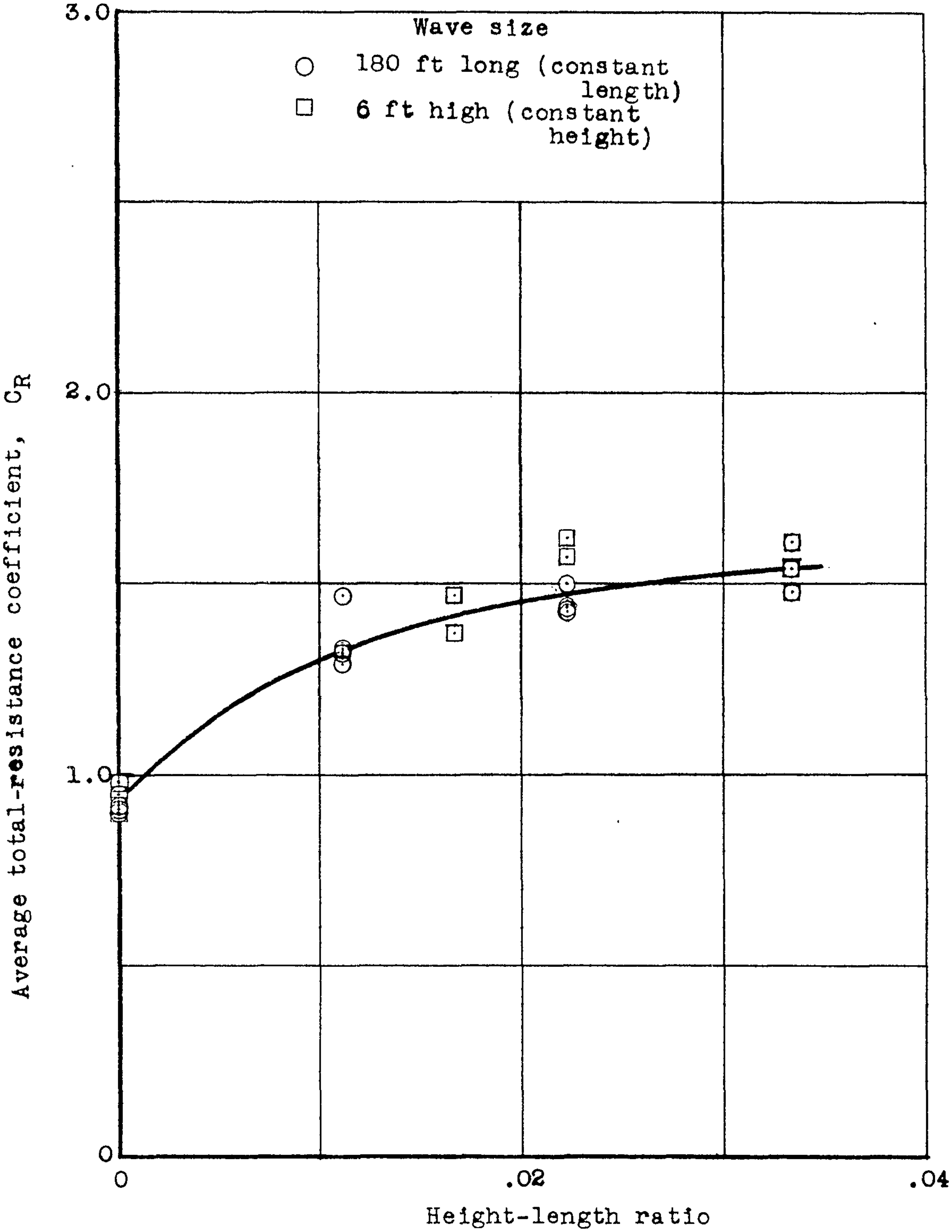


Figure 5.- The effect of wave height and length on resistance. Speed coefficient, 10.1; elevator deflection, $0^{\circ}$; center-of-gravity location, $0.36\bar{c}$; angle of dead rise, $20^{\circ}$; gross-load coefficient, 5.85.

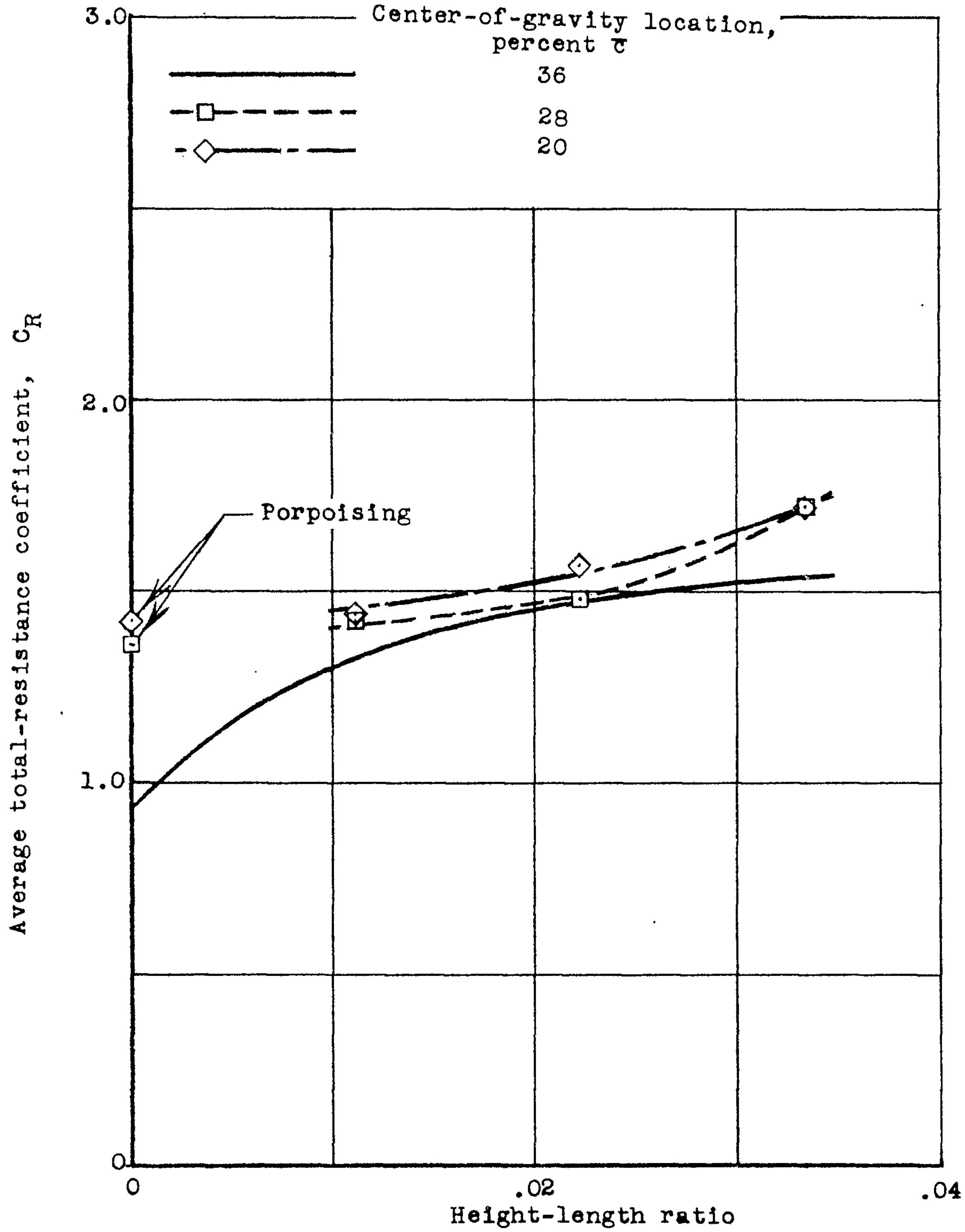


Figure 6.- The effect of wave height on the resistance for three locations of the center of gravity. Speed coefficient, 10.1; elevator deflection, 0°; angle of dead rise, 20°; gross-load coefficient, 5.85; wave length, 180 feet.

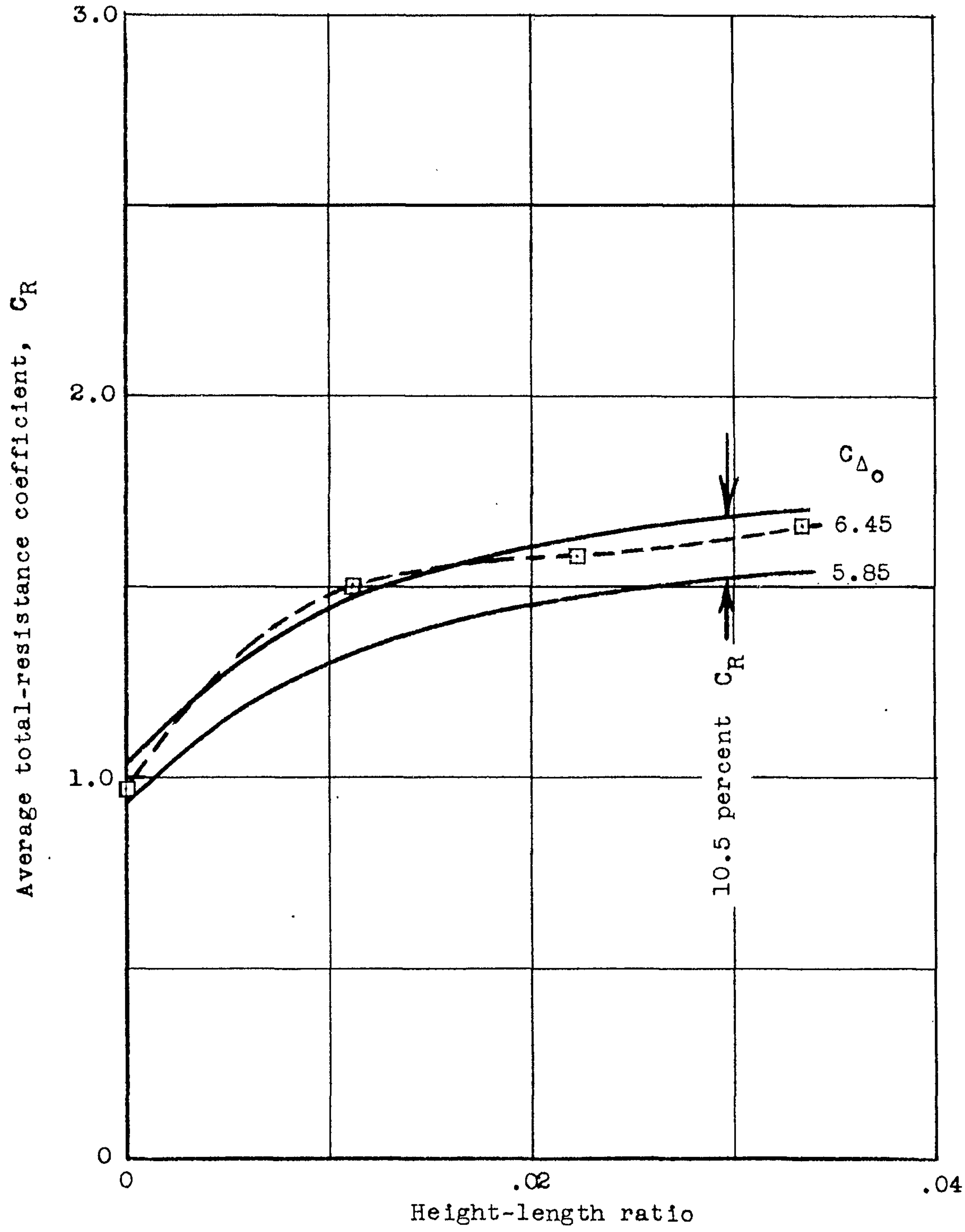


Figure 7.- The effect of wave height on resistance at two load conditions. Speed coefficient, 10.1; elevator deflection, 0°; center-of-gravity location, 0.36$\bar{c}$; angle of dead rise, 20°; wave length, 180 feet.

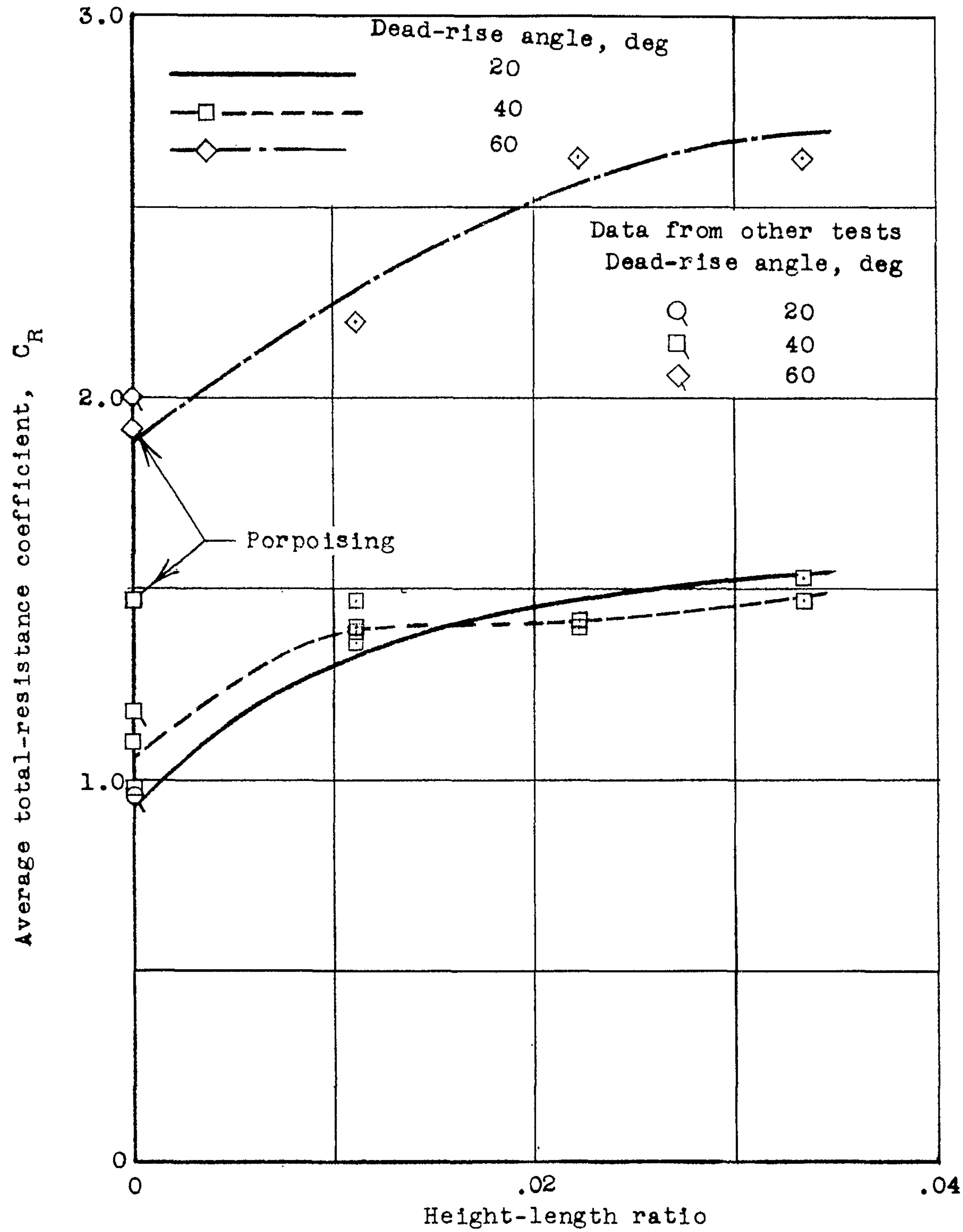


Figure 8.- The effect of wave height on resistance for three dead-rise angles. Speed coefficient, 10.1; elevator deflection, $0^{\circ}$; center-of-gravity location, $0.36\bar{c}$; gross-load coefficient, 5.85; wave length, 180 feet.



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An evaluation was made of the resistance of a high-speed seaplane in waves of three heights. Various conditions were investigated for a seaplane having a dead-rise angle of 20°, a length-beam ratio of 15, and a wing loading of 120 pounds per square foot. The resistance was greater in waves than in smooth water and increased with wave height. The increase was greatest between hump speed and take-off (in 6-foot waves the maximum increase was 65 percent at a speed equal to 70 percent of getaway speed). The increase in resistance was nearly the same with dead-rise angles of 40° and 60° as with the 20° dead-rise angle.

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A BRIEF INVESTIGATION OF THE EFFECT OF WAVES ON THE TAKE-OFF RESISTANCE OF A SEAPLANE. Elmo J. Mottard. April 1956. 17p. diagrs., photos. (NACA RM L56B09)

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An evaluation was made of the resistance of a high-speed seaplane in waves of three heights. Various conditions were investigated for a seaplane having a dead-rise angle of $20^{\circ}$, a length-beam ratio of 15, and a wing loading of 120 pounds per square foot. The resistance was greater in waves than in smooth water and increased with wave height. The increase was greatest between hump speed and take-off (in 6-foot waves the maximum increase was 65 percent at a speed equal to 70 percent of getaway speed). The increase in resistance was nearly the same with dead-rise angles of $40^{\circ}$ and $60^{\circ}$ as with the $20^{\circ}$ dead-rise angle.

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1. Hydrodynamic Configurations - General Studies (2.2)
2. Hulls, Seaplane - Length-Beam Ratio (2.3.1)
3. Hulls, Seaplane - Dead Rise (2.3.2)

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II. NACA RM L56B09

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